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Evaluation of structure and natural regeneration status of woody plant species in sudanian domain : Case of eastern part of National Park of Sena Oura, Chad

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***Abstract*— *Many scientific studies confirmed that plants have an important ecological role maintaining the productivity of the environment and regulating the global climate. In order to valorize the wild phytogenetic resources for the efficient in situconservation and sustainable use in sudano-zambezian region, a study was carried out in sudanian domainprovidingquantitative informations on the community structure and natural regeneration status of woody plant species.The study site is the eastern part of National Park of Sena Oura in Chad. Adults plants (trees and shrubs) were systématically collected in 10 linear transects (20 m x 1000 m). Juvenile plants (saplings and seedlings) weresystematically collected within 40 plots (20 m × 20 m). These plots were randomly stablished in the transects, at a rate of four plots per transect.In total, 84 adults plants species grouped in 58 genera and 29 families and 66 juvenile plants species grouped in 45 genera and 27 families were inventoried. Bell andreverse J-shaped patterns of selected woody species were identified.The stand regeneration status wasgood.The stand regeneration rate were SRR = 52.29% and Hymenocardia acida (SIR = 17.95%), Combretum collinum (SIR = 14.12%), Annona senegalensis (SIR = 6.67%) and Isoberlinia doka (SIR = 6.22%) had the most important specific index of regeneration. The specific structures showed that the structure of the total stand is the result of the dynamics of all species and their interactions.The global stand regeneration status was good.The obtained results provided quantitative informations on the community structure and natural regeneration status of woody plant species for the efficient conservation and sustainable use.*

***Keywords*— Structure, regeneration status, wild phytogenetic resources,in situ conservation,sudano-zambezian region, forest dynamic.**

I. INTRODUCTION

Sudanian domain is the phytogeograpical area loacted between the sahelian domain (drier) and the guineo-congolese domain (semi-deciduous moist dense forest).The National Park of Sena Oura (NPSO) is the third National Park in Chad and it covered 73520 haarea. It was created by Law N° 011/PR/2010 of 10 June 2010 on the initiation of the local communities of the cantons Dari and Goumadji and one of the main objectives of which was to propagate, protect and conserve wild animal and plant species.The vegetation of easthern part of this Park is rich in plant species (85 species) that *Isoberlinia doka*,*Burkea africana*, *Daniellia oliveri*, *Terminalia laxiflora*, *Datarium microcarpum*, *Monotes kerstingii* and *Anogeissus leocarpus* are the most abundant (Todou et al. 2017a). Many scientific studies confirmed that tropical ecosystems are the most rich in biodiversity, particulary in plant biodiversity. These plants have an important ecological role maintaining the productivity of the environment and regulating the global climate(Quijas et al. 2012). They provide food for humans and animals, serve as medicine basis and construction materials as well as combustible. Somes wild fruits are edible. They are sold locally or sold after being processed locally (Todou et al. 2017b).They also protect the land from wind and water erosion, stabilizing the water cycle, facilitate the process of evaporation. They serve to absorb carbon dioxide to reduce global warming, give off oxygen, and renew the atmosphere.The main mission of protected areas is to conserve plant populations, specific diversity or genetic diversity. They also act as buffers against anthropogenic or natural uncertainties, including natural disasters and climate change.

Despite their richness in biodiversity and their usefulness for humanity, tropical ecosystemsare facing a lot of pressure from human as well as natural phenomenon to ensure sustainable improvement of the resources

(Aubertin and Vivien 1998).Humans are still dependent for a large part of his natural environment. They get all that is necessary for their daily survival. The impacts of anthropogenic activities are negative on biodiversity (Akpagana and Bouchet 1995). On the other hand, in almost all sub-saharan african countries, *in situ* conservation policies lack rigor in their design and implementation and have failed. For example, protected areas are generally abandoned and are transformed into plantations, feeding areas and zones of anarchic woodcutting (Akpagana and Bouchet 1994). Currently,few studies on plant biodiversity and its natural regeneration are carried out in sudano-zambezian region.It is known that studies on floristic composition, structure and natural regeneration in forests are instrumental in the sustainability of forests since they play a major role in the conservation of plant species, and the management of forest ecosystems as a whole (Ssegawa and Nkuutu 2006). These studies are imperative to identify and develop the potential for innovations derived from plant richness, particularly those of the developing countries and these studies becomes more imperative in the face of the ever increasing threat to the forest ecosystem. They are also help to understand the dynamics of woody vegetation (Adane 2011).

In easthern part of NPSO, Todou et al. (2017a) had study floristic composition, diversity and ecological importance of woody plants. The resultsgave a general idea of the diversity of ligneous plants in the Sudanian area considering all its phytogeographical sectors.The present study enables to fill some of the information gaps especially of structure and natural regeneration. The idea is to provide quantitative informations on the forest restoration and specific information for conservation measureswhich may be applicable during forest management in all soudano-zambezian region. The main objective is tocontribute to efficient conservation and sustainable use of the sudano-zambezian wild plant resources.The specific objectives are: (1) to evaluate stand structure and individual structure of most abundant species as well as (2) to evaluate the natural regeneration status.

II. MATERIALS AND METHODS

Study area

National Park of Sena Oura is located in the Department of Mayo-Dallah, Mayo-Kebbi West Region. It is located between 8°25'43" and 9°13' 06" North latitude and 13°58'47" and 15°30'09" East longitude. It is located at an altitude of between 350 and 671 m and it is cross-border with the Bouba-Ndjidda National Park in Cameroon (fig. 1).

This study was carried out in the eastern part of the Park, limited to the western part by the river 'mayo sena oura. The NPSO is located in the Sudanian domain (sudano-zambezian region) according to the phytogeographic subdivision (Letouzey 1985). The climate is of the tropical sudano-guinean type with a dry season which extends from October to April and a rainy season from May to September. Annual cumulative rainfall is about 900 to 1200 mm per year. The hydrographic network consists of rivers flowing between July and September (Bemadjim 2014). The vegetation is a wooded savanna identical to that of the National Park of Bouba Ndjidda but with the particularity of sheltering in the zone of confluence of the streams, vegetation of guineo-sudanian type and forests gallery along the rivers.

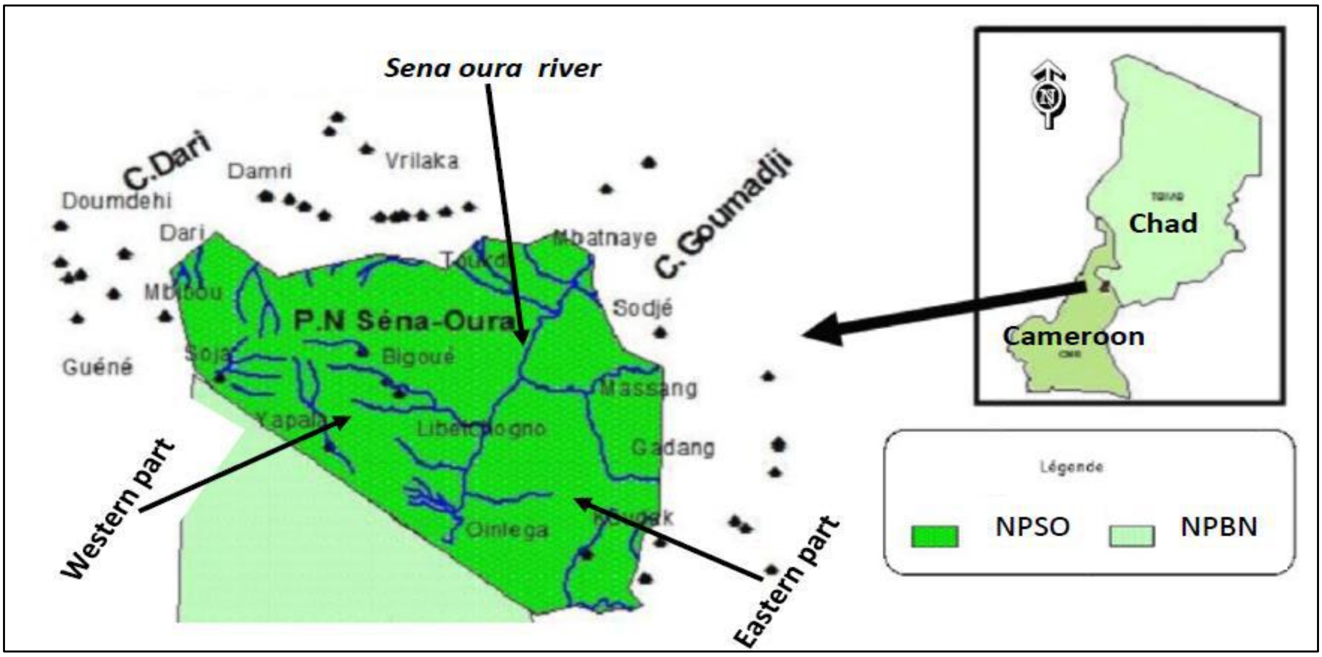

Fig.1 : Location map of study site.

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Data collection

The inventory was done during four months (April-May-June-July 2016).Data collection for adult plants (adult trees and shrubs) was done in 10 linear transects (20 m x 1000 m).These transects were established about more than 500 m one away from each other in order to cover the eastern part of the Park and to represent the maximum of species. In total, 20 ha were surveyed. Juvenile plants (saplings and seedlings) collection was done within 40 plots (20 m × 20 m)randomly stablished in the transects,at a rate of four plots per transect. Within each plot, all juvenile plants were systematically counted. Scientific identification of the most common species was done directly in the field whenever possible. Some specimens were collected in order to authentify scientific names in laboratory of Agriculture and Development Research Institute (IRAD) in Maroua and by botanists of University of Maroua (Cameroon).

Data analysis

The stand structure and specific structure of the eight most abundant adult plant species were assessed through histograms constructed by using the density of individuals (Y-axis) categorized into height and diameters classes (Peters 1996).

All recorded data of plots were pooled and the total number of species were tallied. Using the pooled data, number of species, of genera and of families were calculated in order to evaluate their richness.

The number of juvenile plants was compared with those of adult plants. According to Dhaulkhandi et al. (2008) and Tiwari et al. (2010), there is good regeneration if number of juvenile plants> number of adult plants;there is fair regeneration if number of juvenile plants ≤ number of adults plants; there is poor regeneration if the species survives only in juvenile stage (number of juvenile plants may be <, > or = number of adult plants). If a species is present only in an adult form it is considered as no regenerating. Species is considered as new in the stand if the species has no adult plants but onlyjuvenile plants.

The Shannon Weaver index was calculated according to formula:

$$\mathrm{H} = -\sum_{S=1}^{S} (Pi * \ln(Pi))$$

The diversity is low if H < 3; the diversity is moderate if 3 ≥ H > 4 and the diversity is high if H ≥ 4 (Yédomonhan 2009).

The equitability index of Pielou was calculated using the formula:

$$\mathrm{J} = \frac{\mathrm{H}}{\mathrm{Hmax}} = \frac{\mathrm{H}}{\ln(\mathrm{S})}$$

J ranges between 0 and 1. One species is present in the site if J = 0 and all species have same probability if J = 1. This index means that the degree of diversity reaches the possible maximum ratio.

The stand regeneration rate(SRR) was calculated accordingPoupon (1980) formula:

$$\mathrm{SRR} = \frac{\mathrm{JUV}}{\mathrm{ADT} + \mathrm{JUV}} \times 100$$

JUV = number of juvenile plants of stand ; ADT = number of adult plants of stand.

The specific index of regeneration (SIR)was calculated accordingAkpoand Grouzis (1996) formula:

$$\mathrm{SIRi} = \frac{\mathrm{JUVi}}{\mathrm{JUV}} \times 100$$

SIRi = specific index of regeneration of species i; JUVi = number of juvenile plants belonging to species i.

The *Statistical Package for Social Sciences software* version 20.0 (SPSS, Inc., Chicago, IL, USA) and Excel (Microsoft Office 2013) were used for data processing and presentation of the results.

III. RESULTS AND DISCUSSION

Stand structure of adult plants based on height class

The height class frequency distribution of the stand exhibited a tendency towards a reverse J-shaped distribution (fig. 2).The adjustment of the distribution of all adult plants to the mathematical model gave an exponential function ($y = 4350.6e^{-0.74x}$), highly significant ($p < 0.001$, $R^2 = 0.94$), with y = numberof species and x = the center of diameter class.About 44.02% (1670 individuals)were the highest between 6 and 11 m height class. However,23.29%(800 individuals) were inferior to6 m height. This class was represented by shrubs and also juvenile trees. It can therefore be deduced that up to 76.71% of plants were trees more than 11 m height.In this case where all plants species were grouped, reverse J-shaped distribution indicate that there were less and less species possessing greater individuals than 11 m height.This structure which decreased exponentially from small height classes to great height classes testifies to the stability of the total stand, characterized by regular natural regeneration.

Structure of most abundant species based on diameter class

According Todou et al. (2017), 3792 adult plants grouped in 84 species, 58 genera and 29 families, were identified in eastern part of NPSO. The study of structure was based on diameter class distribution of the eight most abundant species. They were *Isoberlinia doka*,*Burkea africana*, *Daniellia oliveri*, *Terminalia laxiflora*, *Datarium microcarpum*, *Monotes kerstingii*, *Anogeissus leocarpus* and *Combretum glutinosum*.

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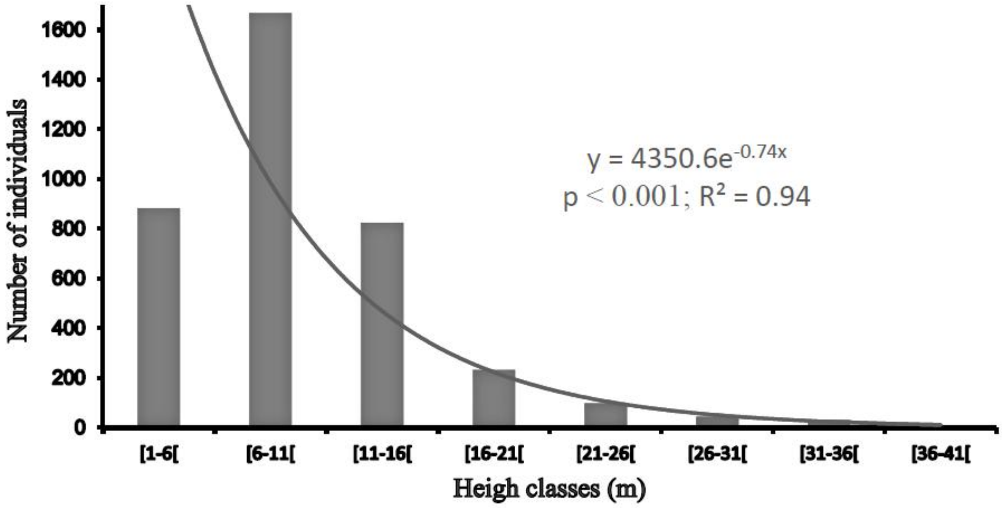

Fig.2 : Vegetation structure of the stand on height class.

By studying species' structure differently, it has been demonstrated that two types of patterns of population structure. In *C. glutinosum* and *B. africana*, diameter class frequency distribution exhibited a tendency towards a bell-shaped pattern (figs 3 and 4). Diameter classes < 10 cm anddiametr class]20, 30]had the least individuals number and diameter class]10,20] had highest individuals number. For the other six species, diameter classe frequency distribution exhibited a tendency towards a reverse J-shaped pattern (figs 5-10). There were*A. leiocarpus* (peack in]10, 20]), *D. oliveri* (peack in]20, 30]), *D. microcarpum* (peack in]10, 20]),*I. doka* (peack in]20, 30]), *M. kerstingii* (peack at diameter < 10 m) and *P. lucens* (peack in]10, 20], but always with individuals of smaller diameter class than these peaks. These specific structures, different from each other, show that the structure based on the height of the total stand was the result of the dynamics of all species and their interactions(Guedjé2002). In eastern part of NPSO, the potential natural regeneration were not negligeable, according the results of specific structures, beacause there was a large number of individuals fell in the smaller diameter classes than the peacks of some species.

In bell-shaped pattern the distribution of individuals of a species in the middle diameter classes is high and low in lower and higher diameter classes. According to Feyera et al. (2007), bell-shaped pattern indicates a poor reproduction and recruitment of species which may be associated with intense competition from the surrounding trees. This similar situation was observed by Kuma and Shibru (2015) in Oda Forest of Humbo Carbon Project (Ethiopia). Inverted J-shaped pattern has shown high distribution of individuals of a species in the lower diameter classes and a gradual decrease towards the higher classes. It has shownalso good reproduction and recruitment potential of the species.Analysis structures for adult plant species could provide more realistic and specific information for conservation measures.

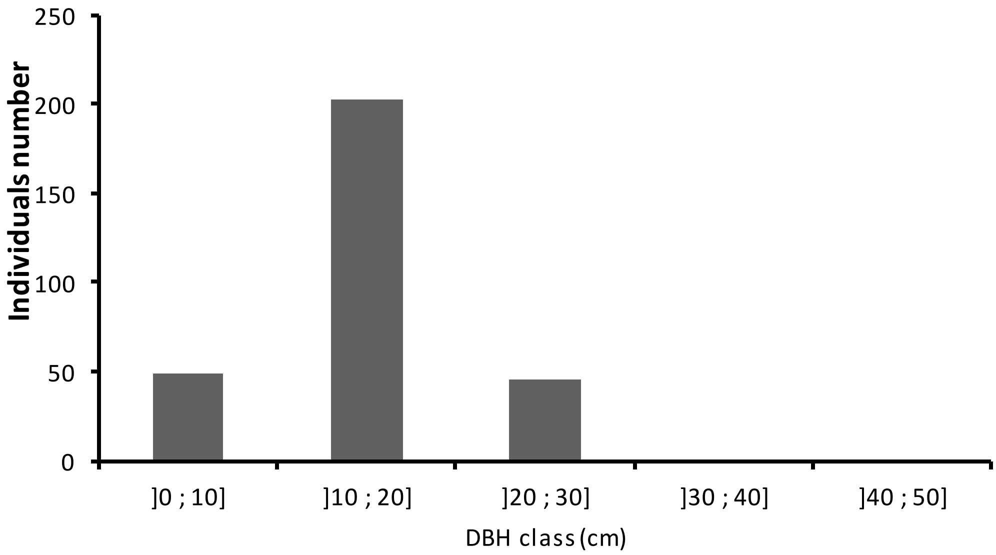

Fig.3 : Structure of C. glutinosum based on diameter class.

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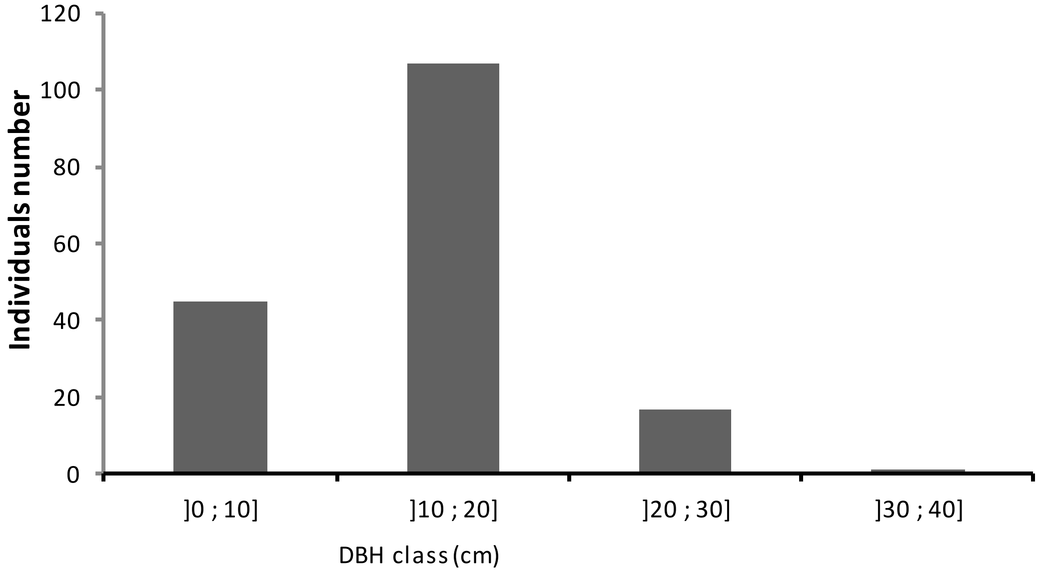

Fig.4: Structure ofB. africana based on diameter class.

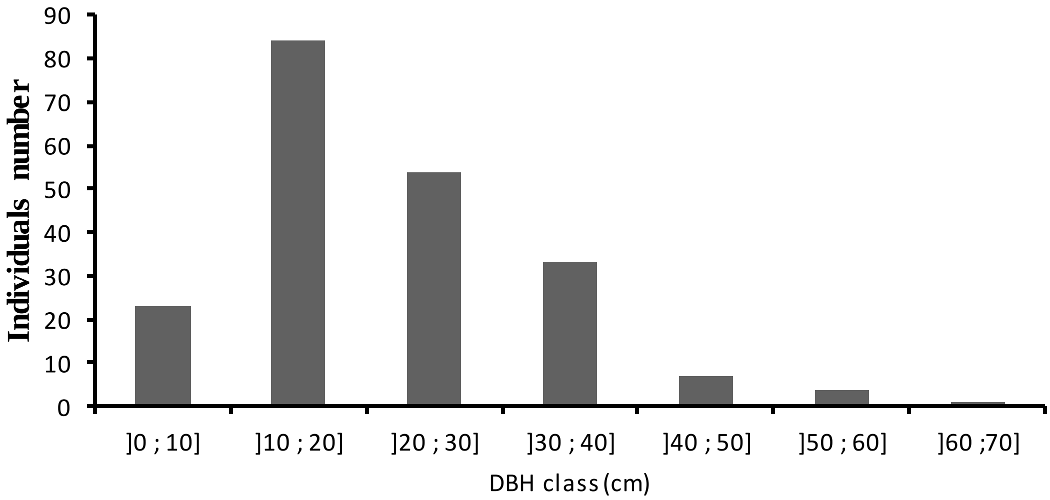

Fig.5: Structure of A. leiocarpus based on diameter class.

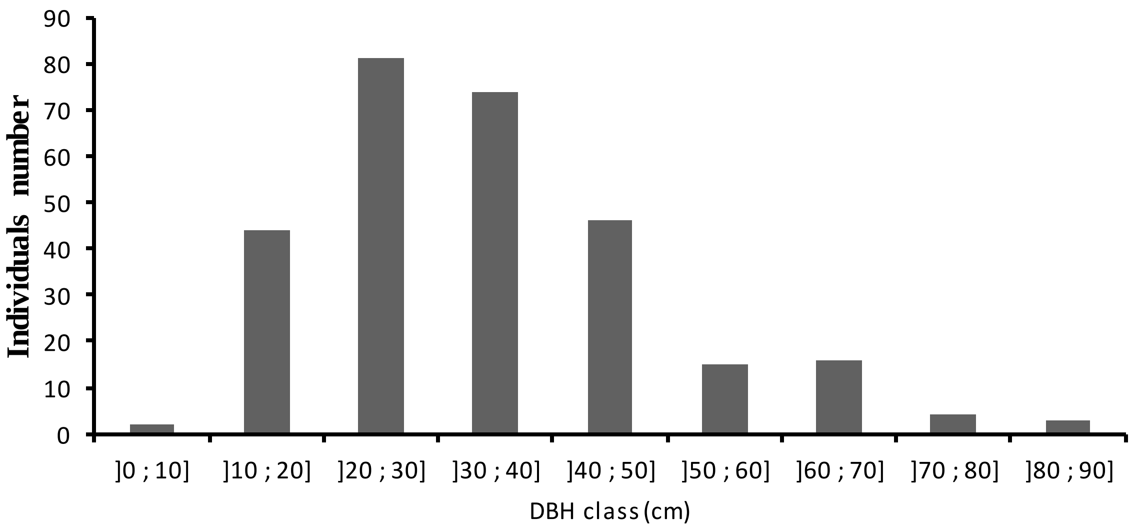

Fig.6: Structure of D. oliveri based on diameter class.

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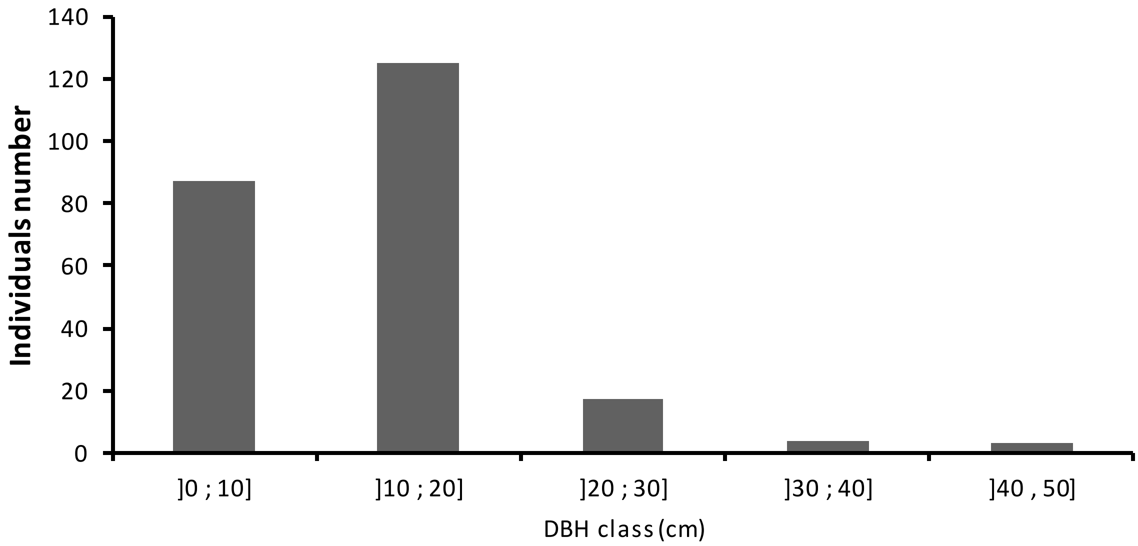

Fig.7: Structure of D. microcarpum based on diameter class.

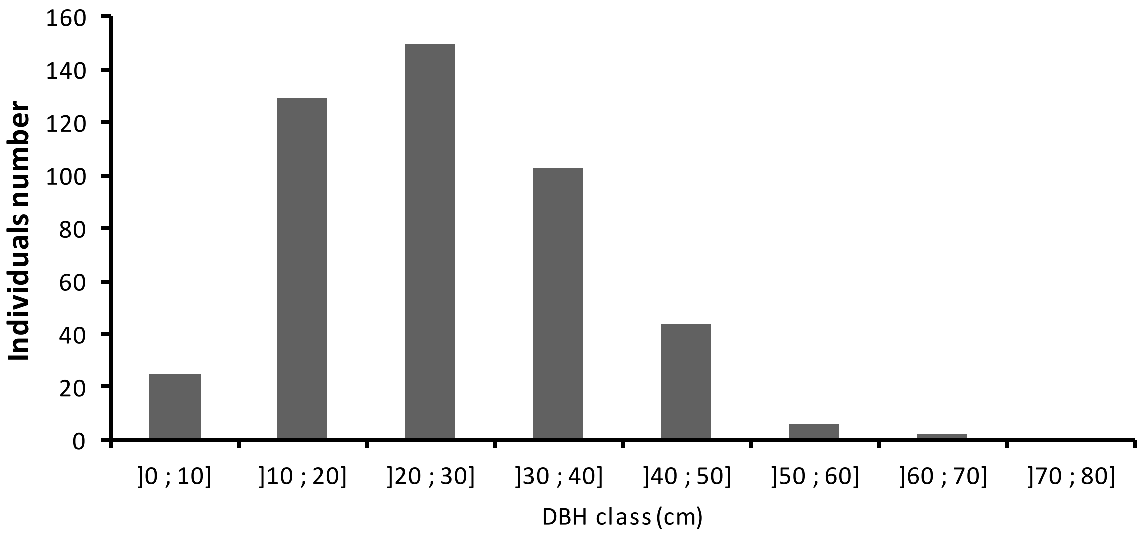

Fig.8: Structure ofI. doka based on diameter class.

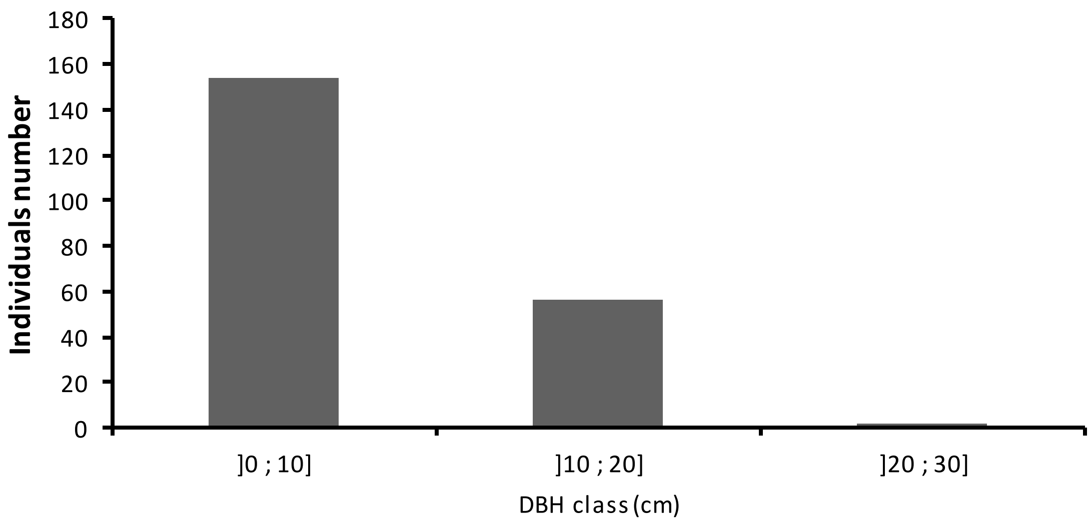

Fig.9: Structure of M. kerstingii based on diameter class.

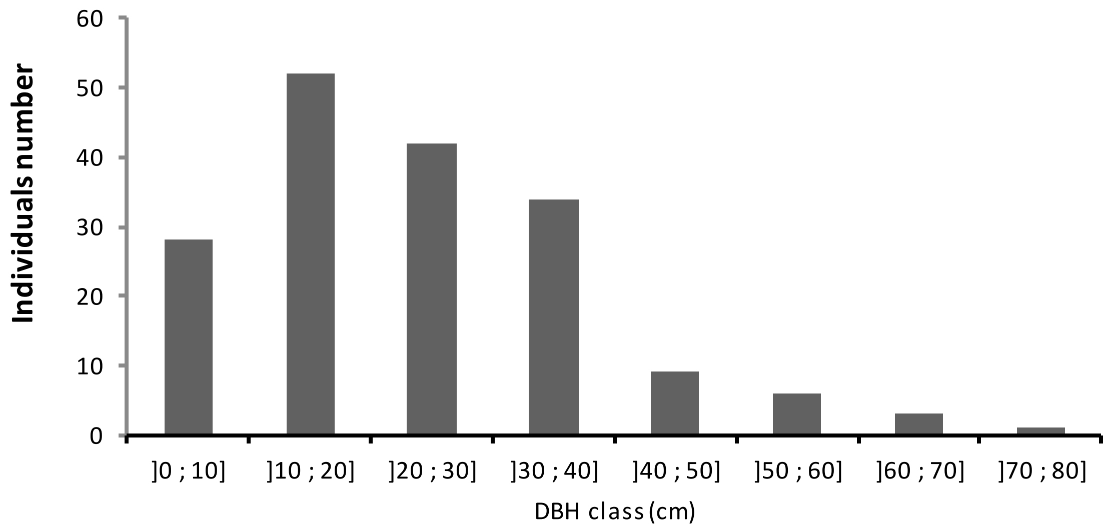

Fig.10: Structure of P. lucens based on diameter class.

Stand diversity of juvinile plants and natural regeneration status

In the stand, there were 66 species belonging to the natural generation flora (number of juvenile plants species). They belonged to 45 genera and 27 families. The number of these juvenile plants species, genera and familes were inferior to those of adult plants. However, according to Dhaulkhandi et al. (2008) and Tiwari et al. (2010), the stand regeneration status was good because the juvinile individuals (Nt = 4146 individuals and D = 2657.67 individuals per ha) was more represented than adult indivuduals (Nt = 3792 invidividuals and D = 189.60 individuals per ha). Juvinile stand diversity (Shannon index = 3.20 and Pielou equitability = 0.76) was comparable to those of adult plants (Table 1).Thisstand diversity was moderated with fairly good equitablility according Yédomonhan (2009) analysis. The Shannon index was usually found to fall between 1.5 and 3.5 and is rarely above 5.0 (Magurran 2004). The found value (Shannon index = 3.20)in this inventory fall within the expected range, but sufficient for sudanian landscapeaccording Todou et al.(2017a).

There were 53 species with good regeneration (densities of juvenile plants were superior to those adult individuals), two species with fair regeneration (*B. africana* and *T. macroptera*) with densities of juvenile plants were inferior to densities of adults individuals and 29 species with no regeneration (no juvenile plants were recorded). On the other hand, 11 species were represented by juvenile plants only. There were *Acacia erythrocalyx*, *Acacia sieberiana*, *Bridelia scleroneura*, *Flueggea virosa*, *Grewia barteri*, *Grewia venusta*, *Grewia vilosa*, *Maytenus senegalensis*, *Psorospermum senegalensis*, *Vitex simplicifolia*, *Ziziphus mucronata*(Table 2).They were considered as new species in the stand according Dhaulkhandi et al.(2008). In Oda Forest of Humbo Carbon Project in Ethiopia, 23.7% represented juvenile plants and 74% represented adults trees (Kuma and Shibru 2015). Combretaceae (13 species), Caesalpinaceae (9 species) and Mimosaceae (8 species) specifically dominated in the studied area (Table 2). It was same to adult plants that Combretaceae (16 species), Caesalpinaceae (10 species) and Mimosaceae (10 species) were specifically dominated in the same site (Todou et al. 2017a).The so called new species could be present in the forest, more or less far from the study site, but dispersed by frugivorous animals. This could justify the important ecological role of animals in a forest ecosystem.

Natural Regeneration is the establishment of trees from seeds that fall and germinate *in situ* (Harmer 2001). It is the basis for understanding the dynamics of woody vegetation. It involves recruitment, juvenile mortality and different stages of development, and survival (Traoré 1997). It can be vegetative or by natural seedling, but in easthern part of NPSO, natural regeneration was assessed by the importance of sapling. The general regeneration important, stand regeneration rate were SRR = 52.29%.This value is not negligible because it is higher than average. It indicates a stability of the total stand assumed in the structural study. Stand regeneration rate of easthern part of NPSO was slightly lower than that of Ngom et al. (2013) in Ferlo Biosphere Reserve (northern Senegal). That was 72%.The importance of regeneration according different species was represented by Specific Index of Regeneration (SIR). Species with the greatest potential for regeneration were*Hymenocardia acida* (SIR = 17.95%) *Combretum collinum* (SIR = 14.12%), *Annona senegalensis* (SIR = 6.67%) and *Isoberlinia doka* (SIR = 6.22%). These species alone accounted for up to 45% of regeneration. Species with low regeneration potential

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were*Grewia barteri*, *Maytenus senegalensis*, *Psorospermum seneglensis*, *Pterocarpus erinaceus*, *Sterculia setigera*, *Terminalia macroptera* and *Ziziphus mauritiana* whith SIR = 0.02% each (Table 2).According Ngom et al. (2013), species with the highest specific index of regeneration are species which regenerate readily by stump in the absence of bushfires. This is the case of Hymenocardiaceae and Combretaceae.

Table.1: Diversity characteristics of each stage of stand development in the study site

Parameters	Adult plants*	Juvenile plants
Number of individuals	3792	4146
Number of species	84	66
Number of genera	58	45
Number of families	29	27
Density (stems.ha^{-1})	189.60	2657.67
Shannon index	3.41	3.20
Simpson index	0.95	-
Pielou equitability index	0.76	0.76

* Results published in Todou et al (2017a)

Table.2 : List of species and their density and their generation status

Families	Species	Adult plants*	Juvenile plants		Status
		D	D	SIR	
Anacardiaceae	*Lannea acida*	0.35	-	-	No
	Lannea barteri	0.1	-	-	No
	Lannea velutina	3.7	9.62	0.36	Go
	Lannea schimperi	0.5	-	-	No
Annonaceae	*Annona senegalensis*	0.7	177.56	6.67	Go
	Hexalobus monopetalus	0.2	-	-	No
Bignoniaceae	*Stereospermum kunthianum*	0.5	37.82	1.42	Go
Bombacaceae	*Bombax costatum*	0.25	1.28	0.05	Go
Burseraceae	*Commiphora pedonculata*	0.55	-	-	No
	Boswellia dalzielii	0.05	1.92	0.07	Go
Caesalpiniaceae	*Afzelia africana*	0.95	10.9	0.41	Go
	Burkea africana	15	10.9	3.08	Fa
	Piliostigma reticulatum	3.95	21.79	0.82	Go
	Piliostigma thonningii	2.6	12.18	0.46	Go
	Tamarindus indica	2.25	30.77	1.16	Go
	Cassia sieberiana	0.35	-	-	No
	Daniellia oliveri	14.1	16.03	0.6	Go
	Detarium microcarpum	11.8	28.21	1.06	Go
	Isoberlinia doka	23	165.38	6.22	Go
	Swartzia madagascariensis	2.25	20.51	0.77	Go
Capparaceae	*Crateva adansonii*	0.1	-	-	No
	Maytenus senegalensis	-	0.64	0.02	Ne
	Maerua angolensis	0.05	-	-	No
Chrysobalanaceae	*Parinari curatellifolia*	0.5	3.85	0.14	Go
Combretaceae	*Combretum collinum*	5.35	375.64	14.12	Go
	Combretum micranthum	0.25	3.85	0.14	Go
	Combretummolle	2.65	3.85	3.42	Go
	Combretum paniculatum	1.1	3.21	0.12	Go
	Anogeissus leiocarpus	10.3	56.41	2.12	Go
	Combretum adenogonium	4.05	13.46	0.51	Go
	Combretum glutinosum	8.75	41.03	1.54	Go
	Terminalia albida	5.15	7.69	0.29	Go
	Terminalia avicennioides	2.95	68.59	2.58	Go

	Terminalia brownii	0.45	6.41	0.24	Go
	Terminalia catappa	1.75	30.77	1.16	Go
	Terminalia laxiflora	12.4	101.28	3.81	Go
	Terminalia macroptera	1.9	0.64	0.02	Fa
	Terminalia mantaly	0.15	-	-	No
	Terminalia mollis	0.45	-	-	No
	Terminalia schimperiana	0.6	-	-	No
Dipterocarpaceae	*Monotes kerstingii*	10.6	24.36	0.92	Go
Ebenaceae	*Diospyros mespiliformis*	0.3	3.21	0.12	Go
Euphorbiaceae	*Croton macrostachyus*	0.35	-	-	No
	Antidesma venosum	0.1	-	-	No
	Bridelia scleroneura	-	27.56	1.04	Ne
	Flueggea virosa	-	1.28	0.05	Ne
	Bridelia ferruginea	0.8	29.49	1.11	Go
Fabaceae	*Erythrina sigmoidea*	0.1	-	-	No
	Pericopsis laxiflora	1.7	-	-	No
	Pterocarpus lucens	8.75	102.56	3.86	Go
	Lonchocarpus laxiflorus	1.1	20.51	0.77	Go
	Pterocarpus erinaceus	0.35	0.64	0.02	Go
Guttiferae	*Psorospermum senegalensis*	-	0.64	0.02	Ne
Hymenocardiaceae	*Hymenocardia acida*	2	477.56	17.95	Go
Loganiaceae	*Strychnos innocua*	2.4	44.87	1.69	Go
	Strychnos spinosa	1.35	55.77	2.1	Go
Meliaceae	*Ekebergia senegalensis*	0.05	-	-	No
	Khaya senegalensis	0.25	1.28	0.05	Go
	Pseudocedrala kotschyi	2.05	26.28	0.99	Go
Mimosaceae	Acacia ataxacantha	0.05	7.05	0.27	Go
	Acacia erythrocalyx	-	7.05	0.27	Ne
	Acacia gerrardii	0.1	-	-	No
	Acacia macrostachya	1.1	3.21	0.12	Go
	Acacia sieberiana	-	1.28	0.05	Ne
	Acacia polyacantha	0.3	2.56	0.1	Go
	Acacia tortilis	0.15	-	-	No
	Albizia zygia	0.05	-	-	No
	Parkia biglobosa	0.05	-	-	No
	Prosopis africana	1.65	21.15	0.8	Go
	Dichrostachys cinerea	0.05	62.18	2.34	Go
	Entanda africana	0.45	2.56	0.1	Go
Moraceae	*Ficus sur*	0.05	-	-	No
	Ficus thonningii	0.05	-	-	No
	Ficus ingens	0.15	-	-	No
Myrtaceae	*Syzygium guineense* var. *macr.*	0.15	-	-	No
Olacaceae	*Ximenia americana* L.	2.9	19.87	0.75	Go
Opiliaceae	*Opilia celtidifolia*	0.3	20.51	0.77	Go
Polygalaceae	*Securidaca longepedunculata*	0.05	17.95	0.67	Go
Rhamnaceae	*Ziziphus mauritiana*	0.05	0.64	0.02	Go
	Ziziphus mucronata	-	3.85	0.14	Ne
Rubiaceae	*Crossopteryx febrifuga*	3.95	24.36	0.92	Go
	Gardenia aqualla	0.6	59.62	2.24	Go
	Gardenia ternifolia	0.55	48.08	1.81	Go
	Morelia senegalensis	0.05	-	-	No
	Sarcocephalus latifolius	1.4	-	-	No
	Feretia apodanthera	0.15	14.74	0.55	Go
Sapotaceae	*Vitellaria paradoxa*	0.2	1.28	0.05	Go

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Sterculiaceae	*Sterculia segitera*	0.35	0.64	0.02	Go
Tilliaceae	*Grewia barteri*	-	0.64	0.02	Ne
	Grewia lasiodiscus	0.1	-	-	No
	Grewia venusta	-	96.79	3.64	Ne
	Grewia vilosa	-	3.21	0.12	Ne
Ulmaceae	*Celtis integrifolia*	0.25	-	-	No
Verbenaceae	*Vitex doniana*	0.05	-	-	No
	Vitex simplicifolia	-	1.92	0.07	Ne

D = density (stems/ha); SIR = specific index of regeneration; Go = Good regeneration, Ne = New species, Fa = Fair regeneration and No = No regeneration; * = results published in Todou et al (2017a).

IV. CONCLUSION

At the end of this study, it was demonstrated the structure of all plants species grouped together was reverse J-shaped distribution characterized by regular natural regeneration. Structure of eight selected species demonstrated two types of patterns of population structure: bell-shaped pattern for two species and reverse J-shaped pattern for six species. These specific structures showed that the structure based on the height of the total stand is the result of the dynamics of all species and their interactions.The diversity of juvenile plants stand was moderated with fairly good equitablilitysimilar to adult plants diversity. The global stand regeneration was good that species with the greatest potential for regeneration were*Hymenocardia acida*, *Combretum collinum*, *Annona senegalensis* and *Isoberlinia doka*. But some species with no regeneraion were recorded too and 11 species were represented by only juvenile plantsproving the ecological role of frugivorous animals.These results of structure and natural regeneration status provided quantitative informations on the community structure and natural regeneration status of woody plant species for the efficient conservation and sustainable use.They may be applicable during forest management.

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